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Abstract: OBJECTIVE To investigate whether correction for prematurity affects executive function scores in school-aged children born very preterm. STUDY DESIGN Executive functions were assessed with standardized neuropsychological tests in 142 children born very preterm (born at 32 weeks of gestational age or with a birth weight of 1500 g) and 391 control children, aged 7-13 years. Four-month age bands were established from the data of control children. Differences between uncorrected and corrected scores were compared against zero difference and between very preterm children born before and after 28 weeks of gestation. Regression models were used to compare the uncorrected and corrected scores of children born very preterm with control children. RESULTS For all executive functions, significant, larger-than-zero differences between uncorrected and corrected scores were apparent in children born very preterm. Mean differences ranged from 0.04 to 0.18 SDs. Weak evidence was found that the effect of age correction is more pronounced in very preterm children born before 28 weeks of gestation than in those born after 28 weeks. Differences in executive function scores between children born very preterm and control children were attenuated if scores were corrected for prematurity. CONCLUSIONS Test scores based on corrected rather than uncorrected age may more accurately determine the developmental stage of very preterm children's executive functions at school age. Potential consequences for clinical and research practice need to be discussed in the future.

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Effects of Correcting for Prematurity on Executive Function Scores of Children Born Very Preterm at School Age

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Objective To investigate whether correction for prematurity affects executive function scores in school-aged children born very preterm.

Study design Executive functions were assessed with standardized neuropsychological tests in 142 children born very preterm (born at ≤32 weeks of gestational age or with a birth weight of ≤1500 g) and 391 control children, aged 7-13 years. Four-month age bands were established from the data of control children. Differences between uncorrected and corrected scores were compared against zero difference and between very preterm children born before and after 28 weeks of gestation. Regression models were used to compare the uncorrected and corrected scores of children born very preterm with control children.

Results For all executive functions, significant, larger-than-zero differences between uncorrected and corrected scores were apparent in children born very preterm. Mean differences ranged from 0.04 to 0.18 SDs. Weak evidence was found that the effect of age correction is more pronounced in very preterm children born before 28 weeks of gestation than in those born after 28 weeks. Differences in executive function scores between children born very preterm and control children were attenuated if scores were corrected for prematurity.

Conclusions Test scores based on corrected rather than uncorrected age may more accurately determine the developmental stage of very preterm children's executive functions at school age. Potential consequences for clinical and research practice need to be discussed in the future. *(J Pediatr 2021;238:145-52)*.

To assess the neurodevelopmental status of very preterm survivors (ie, those born at <32 weeks of gestation), clinical guidelines commonly recommend correcting for prematurity in the first few years of life.[1,2] Clinicians usually do this by subtracting the number of weeks and days a child was born prematurely from the child's chronological age. These recommendations are based on and supported by numerous studies that report a substantial difference between test scores based on the uncorrected and corrected age of infants born preterm when assessing motor and cognitive development.[3-7] The effect of correcting for prematurity has been reported to be largest for those born extremely preterm but was also apparent in infants born moderately and late preterm.[8] Whereas most studies focus on the effects of correcting for prematurity during the first few years of life, these effects may remain relevant well beyond infancy and toddlerhood. In fact, theoretical models and empirical evidence suggest that prematurity should be considered across childhood and into adolescence to accurately estimate cognitive functioning.[9-11]

The need to correct for prematurity may also vary across developmental domains.[12] To date, the effect of age correction in the domain of executive functions, a set of higher-order cognitive abilities that help direct goal-oriented behavior,[13] has not yet been assessed systematically. This is despite executive functions being among the cognitive abilities most frequently affected in children born very preterm.[14,15] Moreover, executive functions, which include inhibition, cognitive flexibility, working memory, and processing speed, develop rapidly across childhood and into adolescence,[13,16] so correction for prematurity may remain relevant throughout child development.

Consequently, this study aims to investigate the effect of age correction on executive function scores at school age. Larger-than-zero differences between uncorrected and corrected test scores are expected for children born very pre-

ADHD	Attention-deficit/hyperactivity disorder
C	Condition
CWIT	Color–Word Interference Tasks
D-KEFS	Delis-Kaplan Executive Function System
NEMO	Neuropsychology and Memory
NKI–RS	Nathan Kline Institute–Rockland Sample
TMT	Trail Making Task
WISC	Wechsler Intelligence Scale for Children, Fourth Edition

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term, and this difference is hypothesized to be larger in very preterm children born before 28 weeks of gestation than in those born after 28 weeks. Further, differences between children born very preterm and typically developing children are hypothesized to diminish once prematurity has been corrected for.

Methods

This study was a secondary data analysis drawing on data assessed in various clinical studies conducted at the University Children's Hospital Zurich and the Children's University Hospital Bern and on data assessed as part of a community sample study. The pooling of data from several studies allowed the assembly of a large dataset of control participants—a prerequisite for the establishment of the narrow age bands necessary to investigate the effect of correcting for prematurity.

The data on children born very preterm stem from 2 Swiss studies. The EpoKids study is an ongoing follow-up study investigating the long-term effect of early erythropoietin administration on executive functions in children born between 26 and 32 weeks of gestational age.[17] The current analysis uses data on the subgroup of children who were assessed between 2017 and 2019 (for details, see Schnider et al[18]). The Neuropsychology and Memory (NEMO) research program was run between 2011 and 2015 and assessed cognitive development and training-induced improvements of cognitive abilities in school-aged children born before 32 weeks of gestational age or with a birth weight <1500 g.[19] The current study includes pretraining data. In total, 142 children born very preterm or with low birth weight were included (EpoKids study: 86, NEMO research program: 56). All children born very preterm were between 8 years, 0 months and 13 years, 5 months at the time of the assessment (uncorrected age; corrected age: between 7 years, 10 months and 13 years, 2 months).

For the control group, data were assembled from several ongoing and completed studies conducted at the University Children's Hospital Zurich and the Children's University Hospital Bern. Control participants were selected if they were within the age range of the participants born very preterm and if the parents reported birth at term (ie, ≥37 weeks and 0 days of gestation), no neonatal complications, no neurodevelopmental or neurologic illness past or present (eg, attention-deficit/hyperactivity disorder [ADHD], epilepsy), and no learning disabilities. Inclusion criteria were met by 108 control children from the EpoKids study, 46 from the NEMO research program, 36 from the Brainfit study,[20] 19 from the Hemispheric Reorganization (HERO) study,[21] 19 from the TeenHeart study,[22] and 23 from unpublished datasets assessed at the University Children's Hospital Zurich.

In addition, data from the Nathan Kline Institute–Rockland Sample (NKI–RS) were included in the dataset. The NKI–RS is an ongoing, institutionally centered community sample of participants across the lifespan.[23] From the NKI–RS sample, data were selected on children who were within the same age range as the children born very preterm. Data were excluded on children for whom birth defects, serious head injury, migraine, meningitis, genetic disorders (eg, Huntington disease), psychiatric disorders (eg, anorexia, autism, or ADHD), heart diseases, cancer, learning difficulties (eg, reading problems), or an IQ <85 were reported. The NKI–RS dataset does not document gestational age. In total, 140 participants of the NKI–RS were selected. The final control group thus consisted of 391 participants.

All studies were approved by either the ethical committees of the Cantons of Zurich or Bern, Switzerland, the ethical committee of the Children's University Hospital Bern, Switzerland, or the Nathan Kline Institute and Montclair State University, Montclair, New Jersey. Parents provided written informed consent before participation.

Executive Function Assessment

The majority of the primary studies used the same tasks to assess 4 executive functions: inhibition, cognitive flexibility, working memory, and processing speed. These were thus the tasks selected for the analyses reported here.

In the Color–Word Interference Tasks (CWIT [Delis-Kaplan Executive Function System; D-KEFS][24]), the child is asked to name color patches (Condition [C] 1) and read color words (C2). C1 and C2 assess processing speed. Then, the child is asked to name the ink color of an incongruent color word (C3: inhibition) and to switch between naming the ink color and reading the color word if indicated by a box around the word (C4: cognitive flexibility).

In the Trail Making Task (TMT [D-KEFS][24]), the child is asked to connect numbers distributed across a sheet of paper in ascending order from 1 to 16 (C2: processing speed) and to switch between connecting numbers and letters in ascending order (C4: cognitive flexibility). For all D-KEFS tasks, the completion time (in seconds) was used as dependent variable.

The Digit Span subtest of the Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV, German Version[25]) was used to assess working memory. The child repeats increasing sequences of numbers in the same or reversed order as presented by the examiner. Sum scores of the forward and backward conditions were both used as dependent variables.

In the primary studies, the tasks that assess executive functions were applied as components of more comprehensive assessment protocols of neurodevelopmental outcome. Some of the study protocols also included magnetic resonance imaging of the brain or an electroencephalography assessment. All tasks were administered by trained examiners and in accordance with the standardized instructions provided by the test manuals[24,25] to ensure reliable data assessment.

Mean education level of the mother and father at the time of assessment was used as a proxy for socioeconomic status because this information was assessed in all the primary studies. The scales to assess parental education level were harmonized between studies by defining the following categories: 1 = no high school graduation, 2 = high school graduation/apprenticeship, 3 = college graduation, and 4 = university degree.

Calculation of Age Band–Specific Scores

The 1-year age bands provided by the D-KEFS[24] are too broad to investigate the effect of age correction, because only children born very preterm who are tested close to their birthdays fall into younger age categories. In contrast, 2-month age bands would place all children born very preterm (ie, <32 weeks of gestation) into a younger age category if age at assessment was corrected for prematurity. However, with the available number of control children (n = 391), the respective comparison groups would have been very small with an average of 11.8 control children per category. Pragmatically, and in accordance with the age bands provided by the WISC-IV,[25] 4-month age bands were constructed for the D-KEFS tasks from the data of the control participants. Each control participant was assigned to the appropriate age category, resulting in an average of 21.7 controls per category (number of control participants per age category presented in **Figure 1** [available at www.jpeds.com]). Individual raw scores were then transformed into age band–specific scores as follows:

$$z = \frac{\text{(raw score of each participant)} - \text{(mean of all control participants of the same age category)}}{\text{(SD of all control participants of the same age category)}}$$

For the participants born very preterm, this transformation was performed twice: once with the scores based on uncorrected age and once with scores based on corrected age at assessment.

The WISC-IV Digit Span test was only applied in a subset of the primary studies, leading to a considerably smaller control group for this task (n = 196). This precluded the establishment of new age band–specific scores from the data on the control group. Instead, the norms of the WISC-IV manual[25] were used: The sum scores of the forward and backward condition were each transformed into scaled scores according to the age norms provided by the WISC-IV manual. For the children born very preterm, again, this was done once with the scores based on uncorrected age and once with the scores based on corrected age at assessment. For better comparison with the D-KEFS tasks, the scaled scores were then transformed into *z* scores.

Statistical Analyses

Demographic variables were compared between groups by χ^2 and independent *t* tests as appropriate. For individuals born very preterm, the differences between uncorrected and corrected scores were calculated (ie, corrected − uncorrected score), with positive values indicating that scores based on corrected age are higher than scores based on uncorrected age. These difference scores were compared against a difference of zero by one-sample *t* tests. Further, they were compared between children born before and after 28 weeks of gestation by independent *t* tests to investigate whether the effect of age correction is associated with the degree of prematurity. To assess whether the effect of correcting for prematurity varies with age at assessment, the difference scores were correlated with age at assessment using Spearman correlation.

Group differences in executive function scores between children born very preterm and control participants were investigated using linear regression models, adjusting for parental education level. Age at assessment was not included into the models because executive function z scores were calculated separately for each age band, zeroing out the effect of age at assessment. Each executive function task was defined as dependent variable in a separate model, once using scores based on uncorrected age and once using scores based on corrected age. To account for missing data in the covariate parental education level, multiple imputation was conducted with Multivariate Imputation by Chained Equation[26] with 5 imputations and 50 iterations. Regression models were then performed with pooled mean and SE of parental education level. Effect sizes of group differences between children born very preterm and controls were calculated by converting the *F*-statistics of the linear regression models to *d*, ie, standardized mean difference between groups while taking into account parental education.[27] Effect sizes of 0.2, 0.5, and 0.8 were interpreted as small, medium, and large effects, respectively.[28] To investigate whether group differences between children born very preterm and controls are present in younger and older children, the analyses were repeated in 2 subgroups: Subgroups were split at 10 years of age (uncorrected age) because in one of the primary studies, namely, the NEMO research program, it has previously been shown that group differences in executive functions were only present in children younger than age 10 years and no differences were apparent after 10 years of age.[19] The significance level was set at $P \leq .05$. Statistical analyses were performed with IBM SPSS Statistics 24 (SPSS Inc) and *R* statistical software, version 4.0.2.[29]

Results

Participant Characteristics

The very preterm and control groups were comparable with regard to sex and uncorrected and corrected age at assessment. By design, gestational age was lower in participants born very preterm. Parental education level was higher in families of control participants. **Table I** shows the participant characteristics of the very preterm and the control group (for sample characteristics of children born very preterm below and above 28 weeks of gestaion see **Table II** [available at www.jpeds.com]). In the very preterm group, year of birth was associated with processing speed (TMT C2; $r = 0.22$, $P = .013$) and working memory (Digit Span forward: $r = -0.19$, $P = .031$; Digit Span backward: $r = 0.27$, $P = .002$) but not with the other measures of executive functions (*r* values ranging from −0.08 to 0.09, all $P > .05$).

Difference Between Scores Based on Uncorrected and Corrected Age in Children Born Very Preterm

When age at assessment was corrected for prematurity, 56.7% of children born very preterm fell into a younger age category. **Figure 2** presents uncorrected and corrected

Table I. Sample characteristics of children born very preterm and control participants

Characteristics	Children born very preterm (n = 142)	Control participants (n = 391)	$z/t/\chi^2$	*P* value
Sex, female, No. (%)	63 (44%)	187 (48%)	0.50	.479
Gestational age (in weeks), mean (SD; range)	29.47 (1.92); 24.71-33.71	39.71 (1.13); 37.00-42.00*	−52.52	<.001
Parental education level,† median (IQR)	3.0; 2.0-3.5‡	3.5; 3.0-4.0§	−8.31	<.001
1/1.5, No. (%)	0 (0)	1 (<1)		
2/2.5, No. (%)	47 (34)	32 (8)		
3/3.5, No. (%)	73 (53)	198 (52)		
4, No. (%)	18 (13)	149 (39)		
Age at assessment (in years), mean (SD; range)	10.50 (1.30; 8.03-13.41)	10.53 (1.60; 7.70-13.66)	−0.21	.833
Corrected age at assessment (in years), mean (SD; range)	10.30 (1.30; 7.84-13.17)	10.53 (1.60; 7.70-13.66)	−1.70	.090

Independent *t*-test (continuous variables); χ^2 (categorical variable).
*Exact gestational age was available for control participants of the EpoKids study only (n = 106).
†Mean education level of the mother and the father (1 = no high school graduation, 2 = high school graduation/apprenticeship, 3 = college graduation, 4 = university degree). For 2 participants born very preterm and 26 control participants, only the mother's or the father's education level was available and was used alone for analyses.
‡For 4 participants born very preterm, information on parental education level was missing.
§For 11 control participants, information on parental education level was missing.

scores (for exact means and SDs, please refer to **Table III**, columns "very preterm group"). Across the whole very preterm group, the differences between scores based on uncorrected and corrected age were significantly larger than zero in all executive function tasks except for one processing speed task (TMT C2; **Table IV**). The mean differences ranged from $z = 0.04$ to $z = 0.18$, with $z \pm 1.0$ equaling 1 SD. The difference score for working memory (Digit Span backward) was significantly correlated with age at assessment ($r = 0.18$, $P = .04$). None of the other

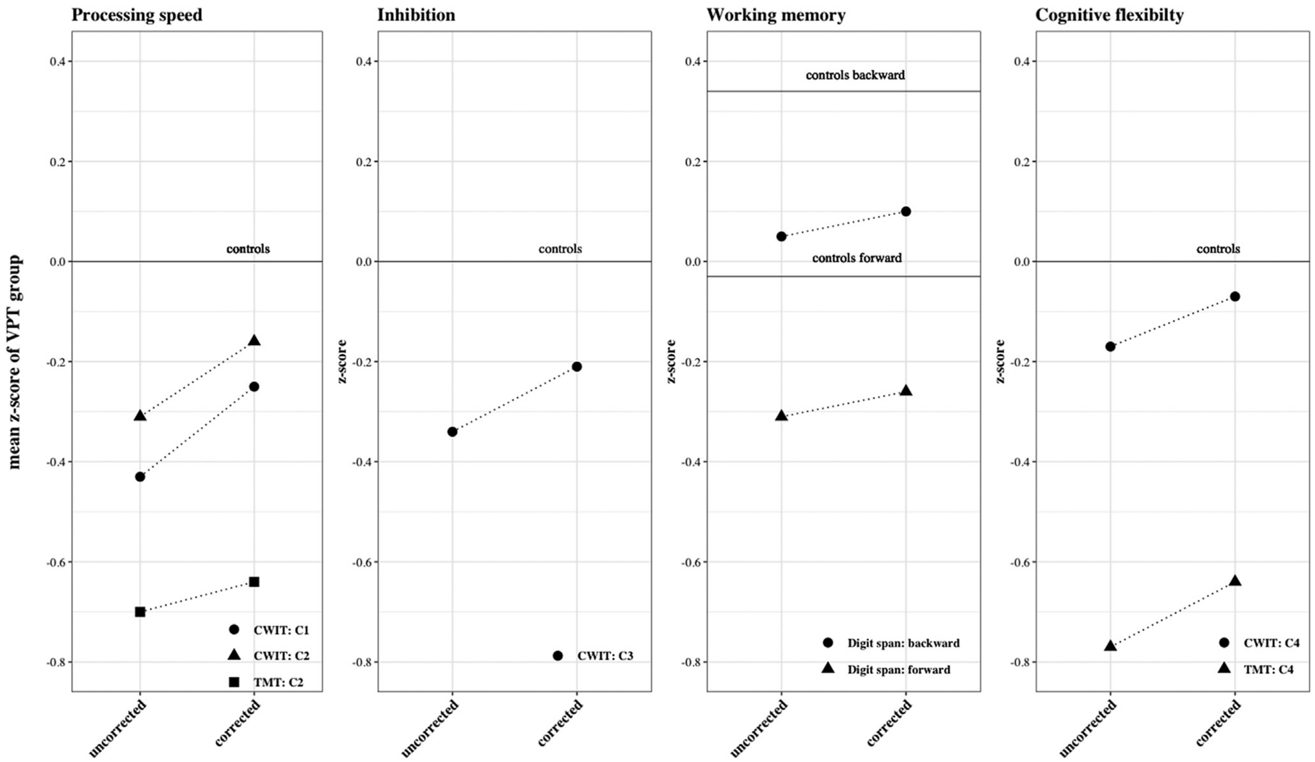

Figure 2. Executive function scores based on uncorrected and corrected age in children born very preterm. The *symbols* represent mean z scores of the very preterm group in the different tasks (*left*: scores based on uncorrected age, *right*: scores based on corrected age; the *dotted connecting line* is for better visualization only). *Horizontal lines* illustrate the means of the control group. For the working memory scores, the norms of the WISC-IV test manual were used and transformed into *z* scores for better comparison with the other tasks. The mean of the control group is −0.03 for Digit Span forward and .34 for Digit Span backward. For all other tasks, the mean of the control group equals zero. Please refer to the text for further details. *VPT*, very preterm.

difference scores were associated with age at assessment, with *r* values ranging from −0.12 to 0.12 (all $P > .05$).

The differences between uncorrected and corrected scores were significantly larger in children born before 28 weeks of gestation than in children born after 28 weeks of gestation in 2 of the 3 processing speed tasks (CWIT C1 and C2). In all other tasks, the difference scores were comparable between the 2 prematurity groups ($P > .05$, **Table IV**).

The Effect of Correcting for Prematurity on Differences in Executive Function Scores Between Children Born Very Preterm and Control Participants

Without correcting for prematurity, regression models adjusted for parental education level revealed significantly lower scores in participants born very preterm than in controls in 2 of the 3 processing speed tasks (CWIT C1: $d = 0.29$, $P = .001$; TMT C2: $d = 0.51$, $P < .001$), 1 of the 2 working memory tasks (Digit Span forward: $d = 0.28$, $P = .030$), and 1 of the 2 cognitive flexibility tasks (TMT C4: $d = 0.40$, $P = .001$). Groups did not significantly differ in any of the other tasks ($d = 0.17$-0.38, all $P > .05$, **Table III**). Repeating the analyses for younger and older children separately revealed similar results compared with the whole group analyses (**Tables V** and **VI**; available at www.jpeds.com).

When the scores based on corrected age were compared between groups, participants born very preterm showed significantly lower scores in 1 of the 3 processing speed tasks (TMT C2: $d = 0.47$, $P = .001$) and in 1 of the 2 cognitive flexibility tasks (TMT C4: $d = 0.36$, $P = .012$). In all other executive functions, scores were comparable between groups ($d = 0.16$-0.36, $P > .05$, **Table III**).

Discussion

Children born very preterm exhibited larger-than-zero mean difference between test scores based on uncorrected and corrected age in all the executive functions assessed: inhibition, cognitive flexibility, working memory, and processing speed. The difference ranged from 0.04 to 0.18 of an SD. This effect size is comparable with what has previously been reported for estimates of cognitive functioning: At school age, one theoretical study and empirical results found a mean difference of 1-5 IQ points depending on whether prematurity was corrected for or not.[10,11] The relevance of such small effects has been debated: It has been argued that a clinical decision to correct for prematurity will depend on the specific context and on the potential benefit for the child, whereas for research purposes, age should always be corrected for to take a known bias into account.[30]

The current study found weak evidence that the effect of age correction is more pronounced in very preterm children who were born before 28 weeks of gestation than in those born after 28 weeks. This is in contrast to previous studies that report greater differences between test scores based on

Table III. Executive functions (z scores) of very preterm and control participants and results of group comparisons using linear regression models

			Scores based on uncorrected age				Scores based on corrected age			
Executive functions	n*	Control group, mean (SD)	Very preterm group, mean (SD)	B (SE)†	*P* value†	*d*‡ [95% CI]	Very preterm group, mean (SD)	B (SE)†	*P* value†	*d*‡ [95% CI]
Processing speed										
CWIT: C1	378/140	0.00 (0.98)	−0.43 (1.32)	0.38 (0.12)	.001	0.29 [0.10-0.48]	−0.25 (1.21)	0.19 (0.11)	.086	0.20 [0.01-0.40]
CWIT: C2	377/139	0.00 (0.98)	−0.31 (1.47)	0.21 (0.12)	.075	0.25 [0.06-0.44]	−0.16 (1.39)	0.06 (0.12)	.628	0.20 [0.01-0.40]
TMT: C2	347/134	0.00 (0.98)	−0.70 (1.55)	0.50 (0.13)	<.001	0.51 [0.32-0.71]	−0.64 (1.71)	0.43 (0.13)	.001	0.47 [0.27-0.66]
Inhibition										
CWIT: C3	371/139	0.00 (0.98)	−0.34 (1.21)	0.19 (0.11)	.079	0.34 [0.15-0.53]	−0.21 (1.20)	0.05 (0.11)	.640	0.32 [0.13-0.51]
Working memory§										
Digit Span: forward	196/133	−0.03 (0.82)	−0.31 (0.79)	0.63 (0.29)	.030	0.28 [0.06-0.50]	−0.26 (0.78)	0.48 (0.29)	.097	0.26 [0.04-0.48]
Digit Span: backward	196/132	0.34 (0.86)	0.05 (0.81)	0.43 (0.30)	.152	0.38 [0.16-0.59]	0.10 (0.81)	0.28 (0.30)	.348	0.37 [0.15-0.58]
Cognitive flexibility										
CWIT: C4	352/137	0.00 (0.98)	−0.17 (1.29)	0.11 (0.12)	.367	0.17 [−0.03 to 0.36]	−0.07 (1.26)	−0.01 (0.12)	.957	0.16 [−0.04 to 0.35]
TMT: C4	336/118	0.00 (0.97)	−0.77 (1.09)	0.39 (0.12)	.001	0.40 [0.20- 0.61]	−0.64 (1.04)	0.30 (0.12)	.012	0.36 [0.15-0.56]

*Control/very preterm.
†B (SE) and *P* values of predictor group in the linear regression models accounting for parental education level.
‡*d* = standardized mean difference between groups while taking into account parental education level.
§Digit Span data were available only for a subgroup of control children. Consequently, scores were transformed into scaled scores according to the test manual and converted into z scores for better comparability (see text for details).

Table IV. Difference between executive function scores based on uncorrected and corrected age in children born very preterm (total group and children born before and after 28 weeks of gestation separately)

Executive functions	n (very preterm)	Mean difference*	SD	Range	*P* value†
Processing speed					
CWIT: C1					
Total sample	140	0.18	0.43	−0.94 to 2.47	<.001
≥28 weeks gestational age	99	0.11	0.30	−0.52 to 1.34	.026
<28 weeks gestational age	41	0.34	0.61	−0.94 to 2.47	
CWIT: C2					
Total sample	139	0.15	0.30	−0.66 to 1.08	<.001
≥28 weeks gestational age	100	0.11	0.27	−0.45 to 1.08	.050
<28 weeks gestational age	39	0.24	0.36	−0.66 to 1.02	
TMT: C2					
Total sample	134	0.13	0.39	−4.54 to 3.07	.325
≥28 weeks gestational age	94	0.02	0.74	−4.54 to 3.07	.325
<28 weeks gestational age	40	0.16	0.73	−1.36 to 3.00	
Inhibition					
CWIT: C3					
Total sample	139	0.13	0.39	−0.88 to 1.58	<.001
≥28 weeks gestational age	100	0.09	0.36	−0.88 to 1.31	.136
<28 weeks gestational age	39	0.22	0.51	−0.63 to 1.58	
Working memory					
Digit Span: forward					
Total sample	133	0.04	0.11	0.00-0.33	<.001
≥28 weeks gestational age	93	0.03	0.09	0.00-0.33	.062
<28 weeks gestational age	40	0.08	0.14	0.00-0.33	
Digit Span: backward					
Total sample	132	0.05	0.12	0.00-0.67	<.001
≥28 weeks gestational age	92	0.04	0.12	0.00-0.67	.220
<28 weeks gestational age	40	0.07	0.13	0.00-0.33	
Cognitive flexibility					
CWIT: C4					
Total sample	137	0.10	0.43	−1.38 to 1.91	.007
≥28 weeks gestational age	98	0.07	0.32	−0.94 to 1.25	.300
<28 weeks gestational age	39	0.18	0.63	−1.38 to 1.91	
TMT: C4					
Total sample	118	0.09	0.36	−1.22 to 1.72	.006
≥28 weeks gestational age	85	0.06	0.30	−1.22 to 1.21	.180
<28 weeks gestational age	33	0.18	0.46	−0.42 to 1.72	

*Difference between z scores based on uncorrected and corrected age (ie, corrected – uncorrected scores; positive values indicate that scores based on corrected age are higher than scores based on uncorrected age).
†Total sample is compared against zero (one-sample *t* test); children born before and after 28 weeks of gestation are compared against each other (independent sample test).

uncorrected and corrected age at lower gestational ages when assessing motor and cognitive functioning of individuals born preterm.[3,4,9] These studies reported effects to be largest in children born extremely premature who were born at and below 28 weeks of gestation. In the current study, two-thirds of the individuals born very preterm were born between 28 and 32 weeks of gestation, and only very few were born before 26 weeks of gestation. This likely reduced the association between the degree of prematurity and the effect of age correction.

Executive function scores of children born very preterm were found to be lower compared with typically developing children if chronological age was used. This is in line with previous studies that report executive functions to be impaired in school-aged children born very preterm.[14,31] Importantly, the current findings provide evidence that these group differences were attenuated if the age at assessment was corrected for prematurity. Although the findings suggest a need to consider prematurity throughout the development of children born very preterm to adequately assess executive functions, further studies are needed to confirm this. Meanwhile, studies may report test scores based on uncorrected age alongside test scores based on corrected age. This may support the interpretation of group differences between children born very preterm and at term. Ultimately, such data will provide the evidence needed to develop recommendations for clinicians, schools, and others involved in the care of children born very preterm. Besides correcting executive function test scores for prematurity, employing motor-free tests may also contribute to a more accurate assessment, as underlying motor impairments may limit test performance. Taking into account basic processing speed may help to provide an unbiased estimate of the developmental status of executive functions following very preterm birth.

In the current study, about one-half of the children born very preterm fell into a younger age category when prematurity was taken into account. Notably, if 4-month age bands are applied, only children born more than 4 months prematurely can fall into a younger age category in any case, and for all other children, this depends on their chronological age at the day of assessment. For example, a child born at 32 weeks of gestation with a chronological age of 8 years, 3 months, will not fall into a younger age category if prematurity is considered, because the corrected age of 8 years, 1 month, falls into the same age category of 8 years, 0 months, to 8 years, 3 months. In contrast, a child born at the same gestational age but assessed at a chronological age of 8 years, 1 month will be compared against the younger age category if prematurity is considered because the corrected age will be 7 years, 11 months. Evidently, the effect of correcting for prematurity, thus, heavily depends on the width of the age bands provided by the respective neurodevelopmental tests. The problems of age-grouping in the neurodevelopmental testing of children has previously been critically evaluated and discussed.[32] Although these problems apply generally when measuring child development, they may be particularly relevant when correcting for prematurity: Many neurodevelopmental tests applied at school-age provide relatively wide age bands, such as the 1-year bands of the D-KEFS.[24] Because correction for prematurity only places the small proportion of children born very preterm assessed on days close to their birthday into a younger age category, a general application is not feasible. In the future, narrower age bands of neurodevelopmental tests—or preferably, an omission of age-grouping altogether[32]—are needed.

Previously, correcting for prematurity has been recommended in the first few years of life to avoid underestimation of motor and cognitive abilities in infants born preterm, and age correction has been considered to be superfluous or even to bear a risk of overcorrection at later ages because children born very preterm are expected to catch up with their peers born at term.[1,2] However, some recent theoretical models and empirical studies have provided evidence that age correction may remain relevant as children grow.[9-11] In the domain of executive functions, it remains a matter of debate whether children born very preterm catch up with their peers born at term and, if they do, at what age.[19,31,33] The current study found weak evidence that differences between children born very preterm and controls vary with age: Effect sizes of group differences were largely comparable between younger and older children (ie, aged below or above 10 years). Ultimately, only longitudinal datasets may provide insight into whether children born very preterm catch up to their peers born at term as they grow up. Importantly for the aim of the current study, the effect of correcting for prematurity on executive function scores was found to be largely the same across the whole age range of the study cohort (ie, 7 years, 10 months to 13 years, 2 months). This implicates that age correction in the domain of executive functions is relevant well into school age. Further studies need to investigate and confirm this in the future.

This study drew on existing data to assemble a large control group within reasonable time and at low cost. However, some limitations inherent to the study design require consideration. Because control participants were not recruited systematically as norm participants, they are not representative of the population; for example, they come from rather high socioeconomic backgrounds (ie, high parental education levels) and children with neurodevelopmental disorders such as ADHD or learning deficits were excluded. Further, the executive function tasks used for further analyses were not selected according to an established theoretical model or methodologic considerations; instead, they were used because they had been applied in the primary studies available. Consequently, the current findings require replication in studies specifically designed to investigate the effect of correcting for prematurity in the domain of executive functions, including the application of a more comprehensive test battery. Also, parental education level of the children born very preterm was high and variance was low. This precluded the investigation of the potential moderating role of parental education level on executive functions that has previously been reported by others.[34] For some of the executive function measures, weak positive and negative associations with the year of birth were found in the very preterm group, namely for 1 measure of processing speed and 2 measures of working memory. Previous studies have reported some evidence that scores of executive functions were lower in children born 2005 compared with earlier eras.[35] Although the current study was not designed to do so, the investigation of temporal trends is essential to monitor neurodevelopmental outcome following very preterm birth.

Correcting for prematurity well into school age should be considered to accurately estimate the developmental stage of executive functions of children born very preterm. To allow this, narrow age bands of normative values are required for appropriate neurodevelopmental follow-up care after very preterm birth. ■

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Data Statement

Data sharing statement available at www.jpeds.com.

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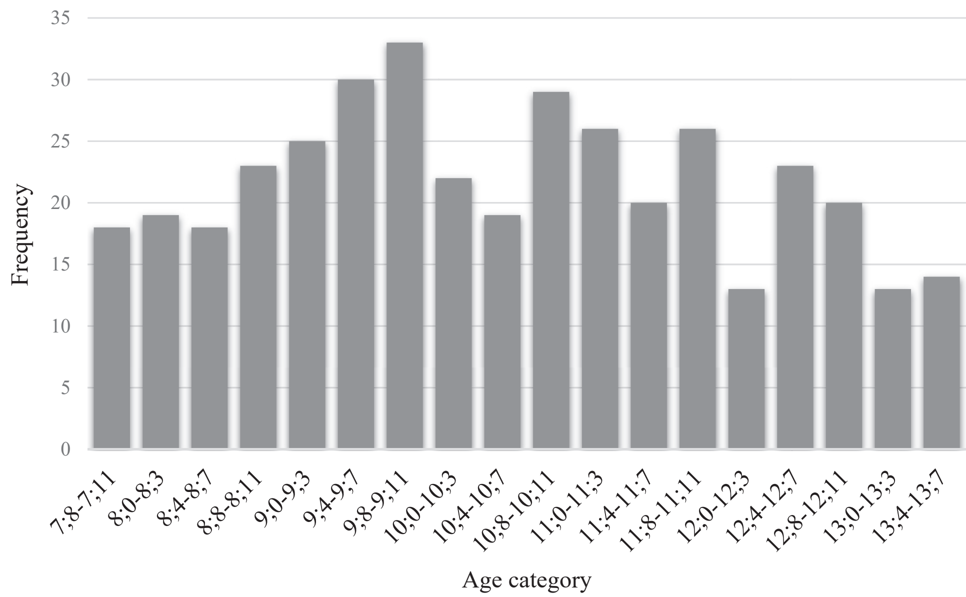

Figure 1. Number of control participants per age category (in years and months).

Table II. Sample characteristics of children born very preterm below and above 28 weeks of gestation

Characteristics	<28 weeks of gestational age (n = 41)	≥28 weeks of gestational age (n = 101)	$z/t/\chi^2$	*P* value
Sex, female, No. (%)	18 (44%)	45 (45%)	0.01	.944
Gestational age (in weeks), mean (SD; range)	27.01 (0.72); 24.71-27.86	30.48 (1.21); 28.00-33.71	−20.97	<.001
Parental education level*				
1/1.5, No. (%)	0 (0)	0 (0)		
2/2.5, No. (%)	15 (38)	32 (32)		
3/3.5, No. (%)	18 (46)	55 (56)		
4, No. (%)	6 (15)	12 (12)		
Median (IQR)	3.0; 2.0-3.5†	3.0; 2.0-3.5‡	−0.17	.865
Age at assessment (in years), mean, (SD; range)	10.72 (1.35; 8.51-13.41)	10.42 (1.28; 8.03-13.05)	1.23	.220
Corrected age at assessment (in years), mean (SD; range)	10.47 (1.35; 8.27-13.17)	10.24 (1.28; 7.84-12.84)	0.96	.340

*Mean education level of the mother and the father (1 = no high school graduation, 2 = high school graduation/apprenticeship, 3 = college graduation, 4 = university degree). Of 2 participants born very preterm at ≥28 weeks of gestational age, only the mother's or the father's education level was available and used for analyses.
†Of 2 participants born very preterm at <28 weeks gestational age, parental education level was missing.
‡Of 2 participants born very preterm at ≥28 weeks gestational age, parent education level was missing.

Table V. Executive functions (z scores) of younger (<10 years) children born very preterm and control participants and results of group comparisons using linear regression models

			Scores based on uncorrected age				Scores based on corrected age			
Executive functions	n*	Control group, mean (SD)	Very preterm group, mean (SD)	B (SE)†	*P* value†	*d*‡ [95% CI]	Very preterm group, mean (SD)	B (SE)†	*P* value†	*d*‡ [95% CI]
Processing speed										
CWIT: C1	158/61	0.00 (0.98)	−0.38 (1.33)	0.30 (0.18)	.098	0.27 [−0.03 to 0.56]	−0.23 (1.32)	0.14 (0.18)	.444	0.19 [−0.11 to 0.48]
CWIT: C2	157/60	0.00 (0.98)	−0.40 (1.47)	0.22 (0.19)	.249	0.33 [0.04-0.62]	−0.23 (1.46)	0.04 (0.19)	.846	0.28 [−0.01 to 0.57]
TMT: C2	144/57	0.00 (0.98)	−0.84 (1.61)	0.37 (0.13)	.006	0.56 [0.27-0.86]	−0.67 (1.48)	0.36 (0.20)	.071	0.53 [0.23-0.83]
Inhibition										
CWIT: C3	152/59	0.00 (0.98)	−0.48 (1.20)	0.23 (0.18)	.191	0.47 [0.17-0.76]	−0.39 (1.20)	0.12 (0.17)	.480	0.45 [0.15-0.74]
Working memory§										
Digit Span: forward	81/56	−0.07 (0.77)	−0.33 (0.81)	0.62 (0.47)	.185	0.23 [−0.11 to 0.57]	−0.29 (0.80)	0.45 (0.47)	.331	0.21 [−0.13 to 0.55]
Digit Span: backward	81/56	0.28 (0.86)	−0.11 (0.78)	0.14 (0.48)	.775	0.44 [0.11-0.77]	−0.11 (0.81)	0.18 (0.49)	.717	0.42 [0.09-0.75]
Cognitive flexibility										
CWIT: C4	143/57	0.00 (0.98)	−0.21 (1.14)	0.04 (0.18)	.824	0.26 [−0.04 to 0.57]	−0.14 (1.06)	−0.03 (0.18)	.857	0.25 [−0.06 to 0.55]
TMT: C4	134/45	0.00 (0.97)	−0.77 (1.09)	0.62 (0.19)	.001	0.57 [0.24-0.90]	−0.64 (1.04)	0.48 (0.19)	.011	0.50 [0.16-0.83]

*Control/very preterm.
†B (SE) and *P* values of predictor group in the linear regression models accounting for parental education level.
‡*d* = standardized mean difference between groups while taking into account parental education level.
§Digit Span data were available only for a subgroup of control children. Consequently, scores were transformed into scaled scores according to the test manual and converted into z scores for better comparability (see text for details).

Table VI. Executive functions (z scores) of older (≥10 years) very preterm and control participants and results of group comparisons using linear regression models

			Scores based on uncorrected age				Scores based on corrected age			
Executive functions	n*	Control group, mean (SD)	Very preterm group, mean (SD)	B (SE)†	*P* value†	*d*‡ [95% CI]	Very preterm group, mean (SD)	B (SE)†	*P* value†	*d*‡ [95% CI]
Processing speed										
CWIT: C1	220/79	0.00 (0.98)	−0.47 (1.33)	0.44 (0.15)	.004	0.31 [0.05-0.57]	−0.25 (1.21)	0.23 (0.14)	.106	0.22 [−0.04 to 0.48]
CWIT: C2	220/79	0.00 (0.98)	−0.24 (1.47)	0.19 (0.16)	.210	0.18 [−0.07 to 0.44]	−0.16 (1.39)	0.06 (0.15)	.705	0.14 [−0.12 to 0.40]
TMT: C2	203/77	0.00 (0.97)	−0.59 (1.55)	0.45 (0.16)	.005	0.47 [0.21-0.72]	−0.64 (1.71)	0.47 (0.18)	.009	0.43 [0.17-0.69]
Inhibition										
CWIT: C3	219/80	0.00 (0.98)	−0.23 (1.21)	0.15 (0.14)	.280	0.24 [−0.02 to 0.49]	−0.21 (1.20)	−0.01 (0.14)	.928	0.22 [−0.03 to 0.47]
Working memory§										
Digit Span: forward	115/77	−0.03 (0.82)	−0.31 (0.79)	0.67 (0.38)	.074	0.30 [0.01-0.58]	−0.26 (0.78)	0.54 (0.37)	.152	0.28 [0.00-0.57]
Digit Span: backward	115/76	0.34 (0.86)	0.04 (0.81)	0.67 (0.39)	.084	0.34 [0.05-0.59]	0.10 (0.81)	0.48 (0.38)	.206	0.31 [0.03-0.60]
Cognitive flexibility										
CWIT: C4	209/80	0.00 (0.98)	−0.17 (1.29)	0.13 (0.15)	.409	0.11 [−0.15 to 0.37]	−0.07 (1.26)	−0.01 (0.16)	.956	0.10 [−0.16 to 0.35]
TMT: C4	202/73	0.00 (0.97)	−0.36 (1.26)	0.26 (0.15)	.090	0.30 [0.0- 0.57]	−0.64 (1.04)	0.19 (0.15)	.204	0.27 [0.01-0.54]

*Control/very preterm.
†B (SE) and *P* values of predictor group in the linear regression models accounting for parental education level.
‡*d* = standardized mean difference between groups while taking into account parental education level.
§Digit Span data were available only for a subgroup of control children. Consequently, scores were transformed into scaled scores according to the test manual and converted into z scores for better comparability (see text for details).